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Report discusses calibration procedures for deriving camera parameters used in the Depth Finder program, and documents a program called Depth Editor, developed as part of this task for manual editing of depth images.

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BST Imagery Generation Task
Final Report

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1. Introduction

This task continues work performed under a previous task (DAAH01-91-D-R005 D.O. 75) entitled "Trainer Methodology Study" and documented in a report of the same name. That report documented two software programs called PathEdit and Depth Finder which are used in creating scenarios for a training device called the Basic Skills Trainer, or BST, which displays moving targets overlaid on bitmapped terrain images. The terrain images for the existing BST being used in the field at this time are artificially generated and not particularly realistic. One aspect of the ongoing BST work is to develop methods of using photographs of terrain as the backdrop to provide better realism. To create BST scenarios using photographs requires a means of defining range and relative depth information for objects in the scene. The range information is needed for scaling targets; the relative depth information for occluding targets. The Depth Finder program is intended as a tool for generating that range and depth information. As discussed in the previous report it includes a camera calibration procedure for determining values of camera parameters and a procedure for extracting true 3D coordinates of objects in the scene relative to the camera from a stereo pair of photographs. The latter procedure depends on good parameter values from the former procedure.

Part of the current task has been an attempt to simplify and standardize the calibration procedure. However a difficulty has emerged in obtaining camera parameters from close range photos taken for calibration purposes and applying those parameters to long-range terrain photos. This is believed to be the result of the change of focus; so far the work has been performed using an auto focus digital camera (Kodak DC50) which has no means of maintaining a fixed focus setting from one photograph to another. Section 2 of this report documents the calibration work for this task.

In order to provide a means of generating the relative depth data needed by the existing BST without stereo photographs and accurate camera calibration parameters, a second program called Depth Editor has been developed as part of this task. This program allows manual editing of the 8-bit depth image used in the existing BST system. The Depth Editor program is documented in section 3.

2. Camera Calibration

The material in the previous report entitled "Trainer Methodology Study" is a prerequisite for understanding this section, particularly section 3.3 of that report on camera geometry and calibration. The parameters of interest are scale parameters c_x and c_y, translation parameters x_0'' and y_0'', and lens distortion parameters k_1, k_2, and k_3. These seven parameters are together called **interior orientation** parameters. **They** relate pixel coordinates in the terrain image to virtual photo coordinates (see **previous report**). On page 19 of the previous report it was stated that:

> "Currently it appears that these interior orientation parameters are consistent enough across various photos
>
> taken with the same camera, that we can treat these parameters as being camera constants."

This statement may in fact hold true for a digital camera with a manual focus setting left in a fixed position between photos. However, at present all work has been performed using a digital camera (Kodak DC50) which does not allow the auto focus system to be overridden. Using this camera it has become apparent that acceptable results cannot be obtained by calibrating the camera at close range and then applying the results to long range photos.

Although the calibration results did not turn out to be acceptable in the sense just discussed, improvements in the calibration procedure developed during this task hopefully will be applicable to the fixed focus case. This will be tested in the near future. In the meantime, since the investigation is continuing, the documentation of the improvements to the procedure given here will be brief.

The calibration procedure depends on the use of control point coordinates. Control points are points with known 3d positional coordinates in some coordinate system external to the camera. In our case, the points are the intersections of lines drawn on poster board and forming a regular grid (see Figure 1). As described in the previous report, the least squares adjustment which computes values of the interior orientation parameters simultaneously adjusts the values of six exterior orientation parameters. These exterior orientation parameters consist of three translation values and three rotation values, which together describe the relationship of the camera coordinate system to the external coordinate system in which the control points have known coordinates. In our case the external coordinate system has two lines of the grid as its x- and y-axes and the line perpendicular to the poster board at the intersection of these two lines as its z-axis.

It turns out that the least squares adjustment does not converge correctly if all the control points lie in a single plane. For this reason two poster boards with grid lines placed at an angle to one another are used. One of the poster boards forms the basis for the external coordinate system. To follow through the calibration procedure as described so far, the coordinates of the grid points on the second board need to be determined relative to the first board, by manual measurement or some other means. To get around this task, new
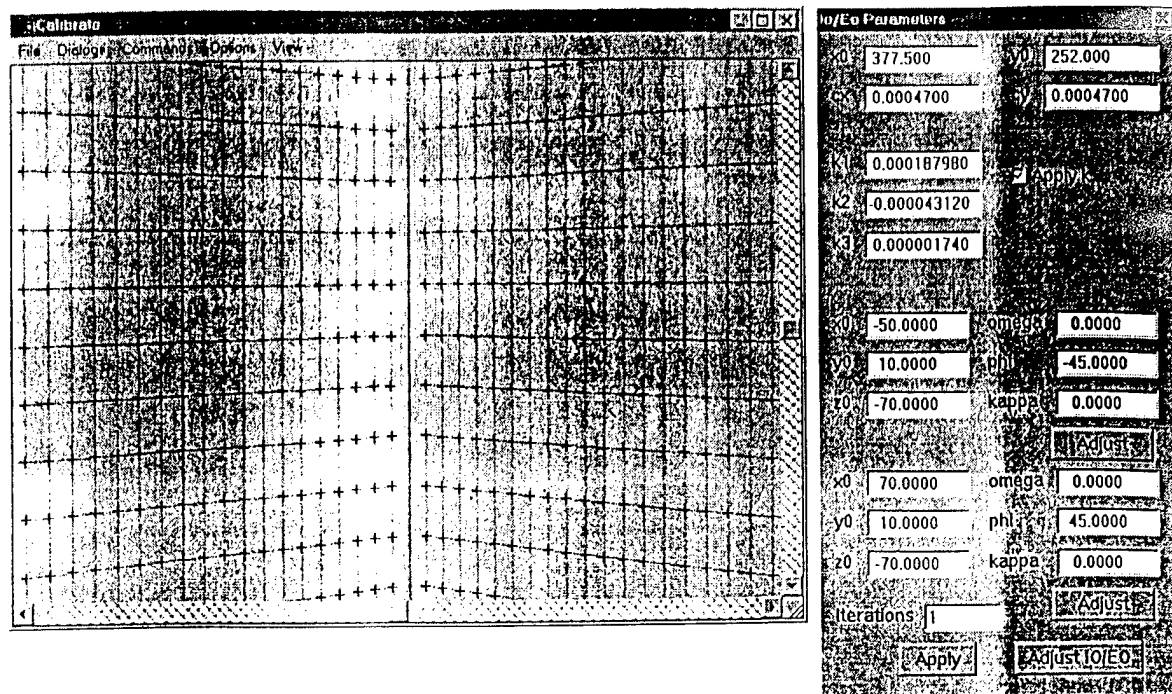
File   Dialogs   Commands   Options   View

Io/Eo Parameters

| x0 | 377.500 | y0 | 252.000 |
| cx | 0.0004700 | cy | 0.0004700 |

k1 0.000187980

k2 -0.000043120

k3 0.000001740

x0	-50.0000	omega	0.0000
y0	10.0000	phi	-45.0000
z0	-70.0000	kappa	0.0000

Adjust

x0	70.0000	omega	0.0000
y0	10.0000	phi	45.0000
z0	-70.0000	kappa	0.0000

Adjust

Iterations 1

Apply   Adjust IO/EO

Figure 1: Calibration Grid and Adjustment Dialog

adjustment equations were derived, incorporating as unknowns another six exterior orientation parameters for the second poster board. This allows all control point coordinates to be given in their natural coordinate system; i.e. as an offset from a grid point on the same board designated as the origin for that board. Rough approximations of each of the two sets of exterior orientation parameters are given as inputs. Values of these parameters appear in the two sets of six readouts toward the bottom of the dialog box as shown in Figure 1. The buttons labeled "Adjust" allow each of these exterior orientations to be adjusted independently, with the interior orientation parameters fixed. Another button, labeled "Adjust IO/EO" performs the adjustment described in the previous report in which both interior and exterior orientation parameters change to most closely fit the measurements to the input control point data.

3. The Depth Editor Program

The Depth Editor program is used to create a depth image corresponding to a given terrain bitmap image. The two images are the same size and resolution, so that there is a one-to-one correspondence between terrain pixels and depth pixels. A pixel in the terrain image represents the visible color displayed at that point, while a pixel in the depth image represents the relative depth at that location. The depth image is 8 bits deep, each pixel having a value from 0 (closest to viewer) to 255 (furthest from viewer). Target paths specify a depth at each location along the path, and the BST makes pixel-by-pixel depth comparisons to determine occlusion of the target by terrain or other targets.

The first step in using Depth Editor is to open a terrain image using the file menu. The terrain image must be a standard bitmap file. The corresponding depth image to be created or edited resides in the same directory as the terrain image and has the same name except for the extension, which is .BMP for the terrain image and .DEP for the depth image. If no corresponding depth image exists at the time the terrain image is opened, the program presents a dialog box allowing the creation of a baseline depth image from a depth table created by specifying a horizon line. A depth table is a table specifying a single depth value for each horizontal line. Thus if the terrain image is 4096 pixels wide by 512 pixels high, the depth table would specify a depth value for line 0, a depth value for line 1, and so on up to line 511.

Figure 2: Depth Editor Main Window and Dialog

Once the baseline depth image based on a depth table has been defined, individual regions of a fixed depth are "painted" in using drawing tools like those found in a paint program. The tools consist of a freehand "pencil" and "eraser," a line tool, rectangle tool, region fill tool, and edge finder. Each of these tools has an icon in the toolbar at the top and a corresponding menu item. The toolbar also has 3 lines of varying width indicating the currently selected brush size. The tools are used to designate a set of pixels as being "selected." These are the pixels to which a depth will be applied when the "Apply" button on the dialog box is hit. The depth to be assigned is the shown in a field on the dialog box; this value may be typed in by the user or taken from the depth table using the button provided for that purpose. Hitting that button causes the depth value from the table at the vertically lowest pixel currently selected to be filled in to depth field, where it can then be assigned to all of the selected pixels by hitting the "Apply" button as indicated above.

Results may be viewed at any point along the way by using options on the View menu to display the depth data in place of or overlaid on top of the image data. The depth data is displayed using a 256-color palette which may be viewed or altered using the "Depth Palette" dialog box. When the depth image is satisfactory it is saved using the "Save" item on the File menu.